CHEMICAL ENGINEERING TRANSACTIONS

VOL. 44, 2015

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Riccardo Guidetti, Luigi Bodria, Stanley Best

ISBN 978-88-95608-35-8; **ISSN** 2283-9216

DOI: 10.3303/CET1544057

Shelf Life Extension of Raspberry: Passive and Active Modified Atmosphere Inside Master Bag Solutions

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Consumers often appreciate small red fruits for their high sensory quality and nutritional value. Furthermore, raspberries are very perishable presenting high respiration rates and a fragile structure; they are easily spoiled by moulds and consequently have a very short shelf life, about 3-5 days.
The general purpose of this study was to investigate the ability of passive and active modified atmosphere packaging in extending the shelf life of red raspberries (*Rubus idaeus* L., cv. Erika). In the case of passive atmosphere, red raspberries were packed inside macro-perforated polyethylene terephthalate (PET) trays inserted in a master bag, made of plastic materials with different permeability and selectivity to oxygen and carbon dioxide. In the case of active packaging, raspberries were packaged into macro-perforated PET trays; 8 of them placed into a cardboard crate, then inserted into an low density polyethylene (LDPE) master bag before sealing, carbon dioxide emitters were introduced. For each trial, the analyses were performed at different times storing the product in a cold dark chamber (5±1 °C, 70 %RH). We performed chemical, mechanical, sensory analyses. Consumer rejection, described by means of the Weibull's equation, was correlated to chemical and physical changes in order to find an acceptability limit useful in defining the product shelf life.
The use of active and passive modified atmosphere packaging resulted in a significant increase on the shelf life of raspberries. This will have a great impact on the waste reduction of this product along the distribution chain, increasing its sustainability.

1. Introduction

Raspberries are non-climacteric fruit, highly perishable for being susceptible to mechanical injury during transportation and picking, water loss, moulds and rots growing during storage. Mould growth can limit the shelf life of fruits (Kim and Wills, 1998; Hertlog et al., 1999). During raspberry life, physiological decay occurs due to the high respiration rates. For all these reasons, the postharvest life of red raspberries is limited to a few days (3-5 days) and only a small percentage of these fruits can be consumed fresh.
During storage, a possibility to control the decreased quality would rely on packaging technologies able to modify the gas composition inside the package, slowing down the fruit metabolism and microorganisms' growth. In fact, it is well known that O_2 and CO_2 concentrations around 10 % and 10-20 %, respectively, are desirable to preserve fresh raspberries quality (Joles et al., 1994). To obtain this proper gas composition, the modification of the atmosphere can be achieved through passive or active solutions (Brody, 2001). In the first case, the permeability of the packaging material and its selectivity towards gasses can be combined with the fruit metabolism to control the equilibrium of oxygen and carbon dioxide in the headspace around the product. In the second case, an active device quickly modifies the gas composition inside the packaging by releasing or absorbing, for example oxygen and carbon dioxide.
Previous works had demonstrated the effectiveness of storage in master bags under controlled atmosphere to extend the shelf life of fresh fruits, but exploiting only the gas permeability of the plastic film and the fruit metabolism to modify the concentration of gases inside the package (Giovanelli et al., 2014; Joles et al., 1994; Van deer Steen, 2002). This system can be economical and easy to use for retailers and producers, but it

Please cite this article as: Adobati A., Uboldi E., Franzetti L., Limbo S., 2015, Shelf life extension of raspberry: passive and active modified atmosphere inside master bag solutions, Chemical Engineering Transactions, 44, 337-342 DOI: 10.3303/CET154405

requires specific films with gas permeability perfectly balancing the fruit metabolism. Furthermore, the achievement of optimal oxygen and carbon dioxide concentrations able to inhibit fruit respiration might be time consuming, so the use of active devices plays a crucial role.
The objectives of this study were: i) to define and optimize a passive solution to extend the shelf life of raspberries; ii)to compare the impact of passive and active solutions on the shelf life of fresh raspberries; iii)to determine the limit of acceptability of raspberries using the survival analysis methodology for the estimate of the shelf life extension resulting from the different packaging solutions. Pre-harvest and handling of fruit are part of the logistic chain; therefore, we did not consider them in these experiments.

2. Materials

2.1 Packaging materials

Table 1 describes the packaging materials used in the experimental plan, including the gas permeability for Oxygen transmission rate (O_2TR), carbon dioxide transmission rate (CO_2TR) and water vapour transmission rate (WVTR).

Table 1: Characteristic of plastic films

	Material	Thickness (µm)	O_2TR ($ccm^{-2}day^{-1}$)*	CO_2TR ($ccm^{-2}day^{-1}$)*	WVTR ($gm^{-2}day^{-1}$)**
A	LDPE	500	500	2600	1.1
B	PA/PE***	150	20	40	3.4
C	LDPE	25	4000	30000	21.7

** 23°C-0 % RH; ** 38°C-90 % RH,*** Polyamide/Polyethylene. The control sample consisted of a macro-perforated PET plus rigid lid providing no barrier to gas and vapour due to the presence of macro-holes.*

2.2 Fruits

We purchased the raspberries in a macro-perforated PET tray (9.5x14x4.5 cm) with a PET rigid lid: this is the traditional sale unit containing 125 g of fruits. Along the supply chain, the trays are transported into cardboard crates (40x30x7 cm) in which eight trays fit. Red Raspberries (*Rubus idaeus* L.) cv. Erika from Northern Italy picked at a commercial ripening state were provided by a local supermarket in Milan and transported to the laboratory where they were immediately stored in a dark cold chamber (5±1 °C, 70 %RH) before packaging.

2.3 Experimental plan

In the first part we studied the influence of different film (A, B and C, described in Table 1) on raspberries shelf life using the passive solution. Master bags containing two PET sale units, heat-sealed without gas flushing were produced using those films. Raspberries were subsequently stored at 5±1 °C (70 %RH) and their quality monitored after storage days 2, 4 and 7.
After the selection of the best master bag material evaluated in the previously section, in the second part, we investigated the active solution using carbon dioxide emitters into the master bags in comparison with passive solution. At this step, an entire cardboard crate (eight trays) was inserted inside a master bag, with or without two carbon dioxide emitters (BioFresh®, nominal capacity 500 cc, Multisorb Technologies Inc., Buffalo, NY, USA). In addition, in this case, master bags were heat-sealed without gas flushing, subsequently stored at 5±1 °C (70 %RH) with quality monitored after storage days 2, 6, 8 and 13.
In all of the cases, we used as control a batch of fresh raspberries not packed into master bags.

3. Methods

3.1 Chemical and physical analyses

Headspace gas composition was periodically sampled through a gas-tight syringe. Oxygen and carbon dioxide were detected and quantified through a gas chromatography (Hewlett-Packard HP 5890 series II) equipped with a thermoconductivity detector (TCD) and a steel column (2 m x 6 mm CTR I Alltech, Milano). The GC oven was set isothermally at 50 °C.
Damaged berries, both physically damaged and mouldy berries, were visually estimated at each sampling time with results expressed as percentage of sound berries.

Colour (L*, a* and b* parameters) was measured for 30 fruits per sampling time through an handheld Tristimulus colorimeter (Konica Minolta CR-300, Tokyo, Japan).

Weight loss was determined gravimetrically by weighting each PET tray at time zero and during the storage using a Technical balance (MP-3000 Chyo Balance corp., Japan). Changes in fruit weight were expressed as percentage of weight loss.

Firmness of raspberries was established using a dynamometer (Zwick Roell Instrumental Z010, Zwick GmbH & Co. KG, Ulm, Germany) through a single compression test on each berry (modified method from Sousa et al., 2007). We assessed at least 30 berries per period. Each berry was positioned under the probe plate (80 mm diameter) and compressed to 60 %deformation using a load cell of 10 kg (100 N), at 2 mm/s test speed and with 5 g pre-load. The method used to assess product firmness intended to measure the structure resistance against the compression applied to the top(peak)-bottom direction. The labour was measured at 60 % of deformation, describing the cavity complete collapse, which is the empty space left by the receptacle after picking. When the deformation overcomes 60 %, the instrument measures the drupelets resistance to compression.

3.2 Consumer acceptability

Forty regular consumers of raspberries (nearly half male, half female) were recruited among students and employees of the University of Milan (Italy), between 21 and 60 years old. At each sampling time, consumers were asked to conduct a visual assessment of the acceptability of raspberries involving each storage time and each packaging condition by answering "yes" or "no" to the following question: "Imagine you are in a supermarket to buy raspberries, would you buy this tray?"

The survival analysis approach was used to process the data: this is a method to assess the time at which an event of interest occurs considering the presence of censored data (Hough et al., 2003).

The results are expressed as the best fitting survival function F(t), using the Weibull's equation (1), which describes the probability of consumer accepting a food product at different storage time (t, days). The fitting was performed for the calculation of α (scale parameter of distribution) and β (shape parameter of the distribution) parameters.

$$F(\mathrm{t}) = e^{-(\frac{\mathrm{t}}{\alpha})^{\beta}} \quad (1)$$

This equation was used to define the time at which the 50 % of consumers rejected the product (Cardelli & Labuza, 2001), when stored in the traditional sale unit (macro-perforated PET tray). Subsequently, this limit was employed to identify the instrumental limit of acceptability of the main quality parameter, thus estimating shelf life extension using different packaging solutions. For survival analysis, we used R software (Bell Laboratories, University of Auckland, New Zealand).

3.3 Statistical analysis

Data were statistically assessed through one-way ANOVA and multiple range test (Tukey method) to reveal significant differences ($p<0.05$) among solutions, using Statgraphics Plus v. 5.1 package.

4. Results and discussion

4.1 Passive solution

During storage in master bag, using different packaging materials, the decrease in O_2 and the increase in CO_2 were registered for all of the samples (Figure 1). Master bags A and B (medium and high oxygen and carbon dioxide barrier, respectively) indicated a faster accumulation of carbon dioxide and a rapid decrease in oxygen reaching values under 5 % during storage time. These conditions induce the cells to switch from aerobic to anaerobic metabolism (Joles et al., 1994). Differently, sample C (the lowest gas barrier film) presented slower oxygen decrease reaching an optimal concentration around 10 % after 4 days in master bag, while, CO_2 reached a roughly 5 % concentration maintained until storage day 7. The ageing process of raspberries is well known to cause colour changes, especially on the red (positive values of a*) and blue (negative values of b*) coordinates of the CIELab colour space (Robbinson & More, 1990; Haffner et al., 2002). As expected, control samples underwent significant a* variation ($p<0.05$) during storage. Samples stored in film A (medium gas barrier) followed a similar decreasing, whereas those stored in the lowest gas barrier master bag (C) maintained the initial colour until day 7, probably due to the respiration processes deceleration and the avoidance of anaerobic conditions. An intermediate behaviour between samples in film A and C was found for Samples stored in film B (high gas barrier).

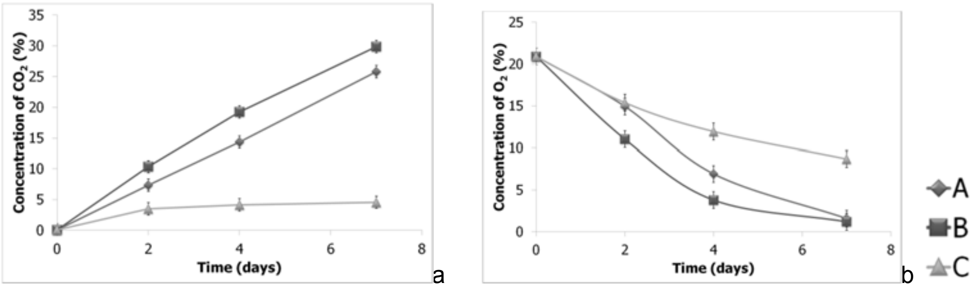

Figure 1: Headspace gases evolution in master bags made with materials A, B and C (a: oxygen; b: carbon dioxide).

High percentages of sound berries (>20 %) characterized control samples right after storage day two, especially because of mould growth. Raspberries packed with medium barrier films (A) did not present any mould development since the level of carbon dioxide was above the toxicity limit (Joles et al.; 1994); however, they were affected by the softening and breakage of drupes reaching >15 % rejection after storage day 7. We observed the most satisfactory behaviour in raspberries storage was found by using the lowest barrier master bags (C) with maximum rejection of 10 % at the final stage of the test.
Fruit firmness is defined as the ability of fruit to maintain integrity, shape and avoid the release of juices. Consumers are able to assess fruit texture through a simple visual evaluation while purchasing; if the product does not meet their requests in term of firmness and colour consumers reject it.
The use of a master bag had a positive impact on raspberries firmness (Figure 2), especially when the film with the greatest gas permeable feature was used (C). In fact, the latter solution was able to maintain the initial quality of berries in terms of firmness until the end of the test (day 7), whereas the control samples were strongly degraded after only day 2.
In addition, the films WVTR seemed to affect the fruits softening process: as evident in Figure 2, it occurred an quickly change in samples stored in film A presenting the lowest WVTR (1.1 g m^{-2} day^{-1}). The presented quality indices indicated that the use of master bags film with low barrier to oxygen, carbon dioxide and water vapour provided a passive atmosphere modification able to maintain the quality of raspberries longer than the traditional packaging in air, up to at least 7 days storage.

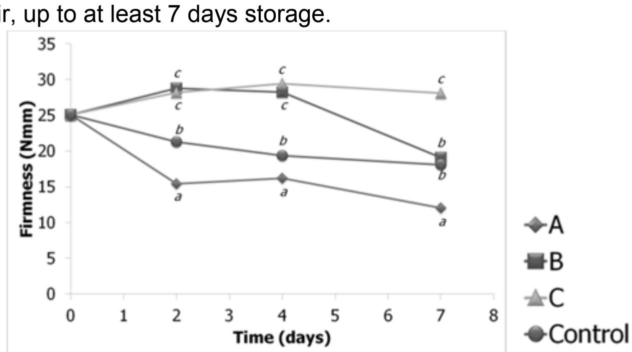

Figure 2: Firmness evolution of raspberries stored in master bag A, B, and C and control samples [a,b,c] different letters for the same time indicate significant differences ($p<0.05$).

4.2 Active solution

The comparison of active and passive atmosphere modification using the master bag made with film C as the distribution unit was assessed . As expected, the presence of carbon dioxide emitters (E samples) resulted in a faster increase in CO_2 concentrations within 2 days, maintaining values above 12 % until the end of the test (Figure 3) due to the balance created by the CO_2 transmission rate in the master bag. This CO_2 level can influence the product respiration, which seemed to be slower as the oxygen level remained at values around 10 % for the entire storage. This condition has been widely reported as optimal to inhibit raspberries respiration without causing fermentation (Joles et al., 1994).
The fruits stored in master bag F without CO_2 emitters were characterised by faster oxygen consumption reaching the undesirable 5 % oxygen concentration; while CO_2 levels raised during storage due to fruits higher respiration ageing.

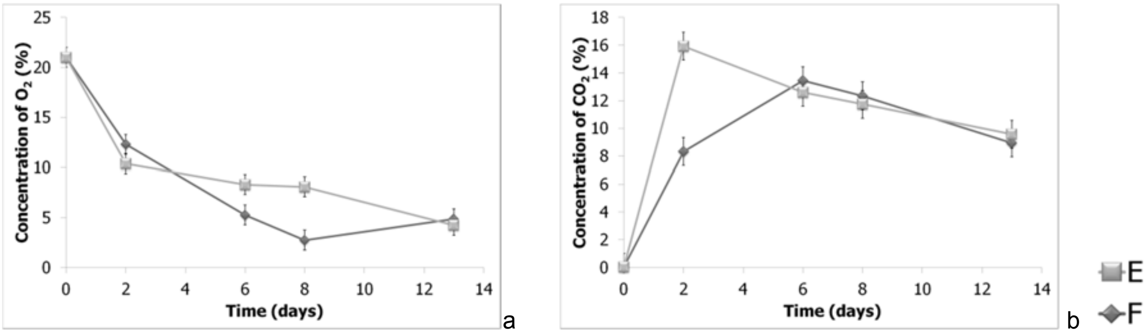

Figure 3: Headspace gas evolution (a: O_2, b: CO_2) in master bags with and without CO_2 emitters (E and F respectively).

Texture is a sensory quality attribute of fruits appreciated by consumers; cell turgor pressure is its major contributor (Sousa et al., 2007).

The ageing of the product caused firmness loss especially in the control samples (Figure 4); in this case, the substantial visual mould growth determined the end of test after storage day 8. The fruits packaged with the active solution (E) indicated higher values of firmness compared with those packed without carbon dioxide emitter. Possibly, the higher initial carbon dioxide concentration was able to decelerate the cell wall degradation activity as well (Beaudry, 1999). The use of master bag itself benefited the maintenance of initial firmness due to its WVTR properties, which enabled a proper water vapour exchange, able to reduce the fruit water loss (thus allowing better turgidity) and avoid the condensation within the package. In fact, both E and F samples presented higher values of texture compared with control samples resulting in greater consumer appreciation.

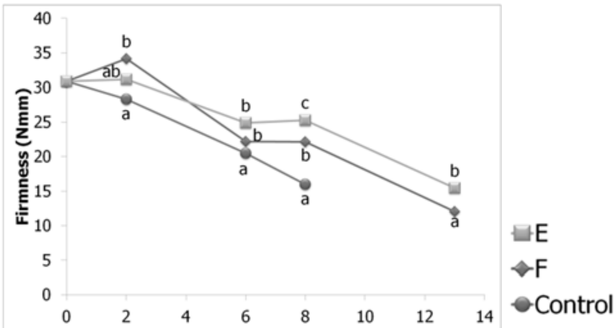

Figure 4: Evolution of raspberries texture during storage in master bags with and without CO_2 emitters (E and F, respectively) and in control samples [a,b,c] different letters for the same time indicate significant differences *($p<0.05$).*

4.3 Shelf life assessment

The consumer rejection was calculated basing on the Weibull model and values of α = 4.12 β = 2.25 (r^2=0.9998) were found in order to define the relationship between failure time and the acceptance probability. The shelf life assessment at 50 % of acceptance was around day 4±0.5 for the control sample.

We carried out the correlation among raspberries' quality indexes assessed during storage into different master bag solutions and the consumer rejection. Our data highlighted that texture, mouldy berries and weight loss had the highest correlation ($r>0.90$, $p<0.05$); the respective acceptability limits were identified. Among the parameters tested, firmness was selected as the main descriptor for product acceptance since its limit was the firstly achieved during storage. Firmness values as 23.4±1.4 Nmm resulted the minimum values for consumers' purchase intention. The shelf life of raspberries packaged into master bags was defined through these values: samples packed without carbon dioxide emitters were characterised by a shelf life of 6±0.5 days, whereas those stored with the emitters, the shelf life reached 8±1 days.

5. Conclusion

The efficiency of packaging master bag system was confirmed to extend the shelf life of raspberries. Not only passive systems can prolong it in 6 days, but also the use of active solutions (i.e. CO_2 emitters) maintained product quality for 8 days. Considering the shelf life assessment through the survival analysis and using a strict limit of product acceptability (i.e. 50 % of consumers' rejection), raspberries proved suitable to be purchased up to 4 days when packaged only into PET trays; 6 days when stored in passive solutions, and 8 days when packaged in active solutions. This shelf life extension can potentially reduce the environmental impact caused by food loss since fresh products are sold for longer time. Further researchers should deeply investigate the different combinations of active devices and shelf life limits established in our study.

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